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ORIGINAL ARTICLE

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Evaluation of Water Quality Using Water Quality Index: Case Study of Sacred Ponds in the Imphal Valley, India

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ABSTRACT

Sacred ponds in the sacred groves of the Imphal valley are an integral part of the Meitei ethnic group's culture, religion and social fabric. Till date, cultural linkages have protected the groves. However, population growth and modernization have impacted the groves at present, with most of the sacred sites and its associated ponds threatened. In the present study, physico-chemical characteristics of water from ten sacred ponds were analysed during 2023-24. The analysis showed that pH ranged from 7.01±0.02 to 8.68 ±0.23 for post-monsoon (PoM) and 7.50±0.04 to 8.82±0.10 for pre-monsoon (PM), electrical conductivity (EC) ranged from 109± 1.53 to 269±2.65 µS cm^{-1} for PoM and 331±1.46 to 681±7.43 µS cm^{-1} for PM, and dissolved oxygen (DO) ranged from 2.9±1.56 to 4.7±2.69 mg L^{-1} for PoM and 2.1±0.14 to 2.9±0.14 mg L^{-1} for PM, respectively. The Water Quality Index (WQI) calculated showed that the ponds are in the very poor or the unsuitable category for drinking. The WQI ranged from 107.29 to 211.91 for PoM and 87.46 to 239.51 for PM, respectively. The observed results suggest the necessity of regular water quality monitoring and assessment. It showed that the restoration of the sacred ponds in the sacred sites is an urgent need of the hour.

1 | INTRODUCTION

Sacred groves are patches of forests or natural vegetation, which can be few trees in a forest or several acres, which are usually dedicated to local folk deities or tree spirits. They are protected by locals due to the religious beliefs and rituals associated (Eco heritage, 2022). Therefore, the sacred sites have witnessed very low levels of disturbance from human exploitation (Khumbongmayum *et al*., 2005). Hence, many sacred natural sites demonstrate rich biodiversity and provide various resources such as water, medicine, food and regulate the ecological conditions of the region associated with human well-being (Millennium Ecosystem Assessment, 2005). India is home to over 1 million sacred forests and 100,000 to 150,000 sacred groves. The Vedic literature has described the practices of maintaining virgin forests, which date back to the pre-Vedic period, i.e. 3000 to 5000 years BC (Wadhwa, 2023). The majority of the sacred groves in India are community-controlled and the protected spiritual sites have deep roots in the cultural fabric of the country (Khumbongmayum *et al*., 2005).

From the Imphal valley, in the Manipur state of northeast India, Devi (2000) reported the presence of 166 sacred groves. The Meitei, the majority ethnic group, have maintained the practice of worshipping the sacred deities known as 'Umang lai' for generations. As a cultural festivity, the celebrations called 'Lai Haraoba' are performed in the groves, which are referred as the 'Celebrations of the Gods', to please the deities in their dwellings (Khumbongmayum *et al*., 2005). Moreover, the sacred groves have been repositories for varieties of valuable, rare or endemic plant and animal species (Devi *et al*., 2025). As such, the groves act as the conservation units of forest, culture and religion for the ethnic group in the valley (Khumbongmayum, 2005).

Today, the sacred groves have seen immense anthropogenic disturbances. As a result of human influence, only a few groves are still well preserved (11%) and most of the sites are partly threatened (58%) or threatened (31%) (Khumbongmayum *et al*., 2005). The rapid urbanization and changing social beliefs alongside the erosion of aged traditional practices have contributed significantly to the degradation of the sacred sites. Moreover, the health of the sacred ponds or 'Lai Pukhri's' associated with the groves is in a dire state in most of the sacred groves.

The sacred ponds, shrouded in myth and legend, became essential to the Meitei ethnic group and catered to their socio-cultural needs (Fig. 1). Today, the process of reconstruction or modernization of the shrines has led to degradation of the associated sacred ponds. Further, pollution and wastewater runoff threaten the ecosystems. However, scientific studies that analyzed the ecological conditions of the sacred ponds are still missing from the region. So far, the sacred ponds have received little interest from the scientific community, which is supported by the lack of research data. Therefore, to add baseline information on the status of the sacred ponds, a pioneer study assessing the water characteristics of ten sacred ponds from the sacred groves in the Imphal valley was carried out in 2023 - 24.

HIGHLIGHTS

- The paper is a pioneer work that assesses the degraded conditions of the sacred ponds in the sacred groves of the Imphal valley.
- The Water Quality Index calculated showed that the sacred ponds are in the very poor or the unsuitable category for drinking.
- At present, there is a need for regular water quality monitoring and restoration initiatives to be taken up for the revival of the sacred ponds.

FIGURE 1 Sacred ponds from the holy sites of (a) Puruk Shoubi and (b) Sana Konung (Radha - Shyam Kunda).

2 | MATERIALS AND METHODS

2.1 | Study Area

The Imphal valley, with an area of 2,238 km^2, is situated in the central part of Manipur, northeast India (Fig. 2). The state with an area of 22,327 km^2, can be subdivided into two regions; the central oval shaped Imphal or Manipur valley, which covers 10% of the state and the surrounding hills with a maximum elevation of 2994 m above mean sea level. The valley is the major hub of industrial growth and population migration from different parts of the state. It is dominated by tropical moist deciduous vegetation and records an annual rainfall of 1500 - 1700 mm. The minimum temperature ranges between 2°and 21°C, and the maximum between 23° and 36° C, respectively. With unique traditions and languages, the Meitei (Hindu) and the Meitei Pangal (Muslim) represent the ethnic groups with the major share of the population in the valley. For the Meitei, each and every locality or 'Leikai' is protected by an 'Umang Lai', which is the guardian of the specific community. Further, the sacred groves and the deities in the abodes are associated with a spiritual sacred pond or 'Lai Pukhri' that is considered holy.

2.2 | Water Sampling

For water sample collection, permission and approval was obtained from the authorities managing the sacred sites. The water samples were collected from ten sacred ponds (N = 30 in total, with three samples collected from each pond) associated with the sacred groves in the Imphal valley (Table 1). The PoM samples were collected during October - November months of 2023 and PM samples during March – April months of 2024, respectively. The samples were collected in 1 L polyethylene bottles, pre-cleaned with HNO_3 and rinsed with distilled water. During sampling, water was collected between a depth of 0.5 m and the water surface. For further laboratory analysis, the water samples preservation was carried out using 1% HNO_3 in order to maintain the pH < 2.

2.3 | Analysis of Water Characteristics

The analysis of the physico-chemical characteristics was performed following standard guidelines provided by the American Public Health Association (2017). pH, EC, total dissolved solids (TDS) and DO were analysed in-situ using a water analyser kit (Systronics Water Analyser 371, India).

The calibration of the instrument for ensuring the reliability of the results (pH, EC and TDS) were performed using standard solutions of HIMEDIA and EUTECH brands. Turbidity (T) was measured using a Nephelometric Turbidity Meter (Systronics Digital Nephelo Turbidity Meter 132), which is calibrated using Formazin solution. Titration of the samples was carried out to estimate alkalinity, chloride, total hardness and calcium hardness, respectively. For the quantification of sodium and potassium, a flame photometer calibrated using standards of the respective ions (Systronics Flame Photometer 128, India) was used. Nitrate and phosphate amounts were estimated using a UV-Vis Spectrophotometer (Systronics UV-Vis Spectrophotometer 117, India) (Table 2).

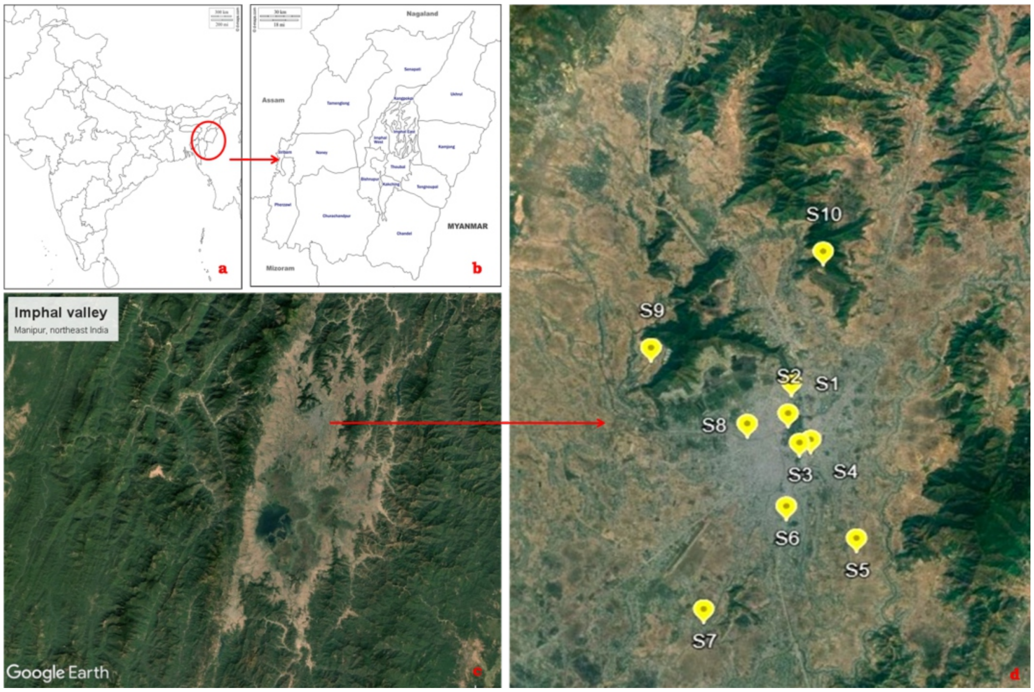


FIGURE 2 Map of (a) India, (b) Manipur, and (c) Imphal valley and (d) locations of the ten sacred groves.

TABLE 1 Sampling locations of the sacred ponds from the Imphal valley during 2023-24.

S.No	Umang lai	Latitudes	Longitudes
S1	Khunthokhanbi	N 24.821°	E 93.940°
S2	Kangla	N 24.807°	E 93.938°
S3	Mahabali	N 24.795°	E 93.943°
S4	Sana Konung	N 24.798°	E 93.948°
S5	Puruk Shoubi Ebudhou Pakhangba Laishang	N 24.733°	E 93.986°
S6	Kakwa Lairembi Sanglen	N 24.769°	E 93.937°
S7	Hiyangthang Lairembi	N 24.726°	E 93.904°
S8	Shri Shri Govindaji	N 24.804°	E 93.922°
S9	Ima Laikhut Lembi Mitinpung	N 24.831°	E 93.877°
S10	Ibudhou Marjing	N 24.874°	E 93.953°

TABLE 2 Methods and instruments used for water analysis of various parameters.

S.No	Parameters	Abbreviations	Instrument/methods
1	pH	pH	Water analyser kit
2	Electrical Conductivity	EC	Water analyser kit
3	Total Dissolved Solids	TDS	Water analyser kit
4	Turbidity	T	Nephelometric Turbidity Meter
5	Dissolved Oxygen	DO	Water analyser kit
6	Alkalilnity	Alk	Titration method
7	Chloride	Cl^-	Titration method
8	Total Hardness	TH	Titration method
9	Calcium Hardness	Ca^{2+}	Titration method
10	Sodium	Na^+	Flame photometer
11	Potassium	K^+	Flame photometer
12	Nitrate	No_3^-	UV-visible spectrophotometer
13	Phosphate	Po_4^{3-}	UV-visible spectrophotometer

2.4 | Water Quality Index

The Water Quality Index for drinking was estimated following published literatures (Yadav *et al*., 2010; Sultana, 2021). For WQI calculation, the drinking water quality standards of the World Health Organisation (WHO) (2022) and the Bureau of Indian Standards (BIS) (2012) were used. Altogether, 13 physico-chemical parameters, such as pH, EC, TDS, T, DO, Alkalinity, TH, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, NO_3^- and PO_4^{3-} were considered. For the calculation, the parameters were assigned a different weight (W_i) in the range of 1 to 5, which is based on the influence of the parameter on overall water quality, with 1 being the least significant and 5 with the most vital influence, respectively (Supplementary Table 1).

The relative weight (W_r) is represented as

$$W_r = W_i / \sum W_i \quad (1)$$

where, i = total number of parameters.

The quality rating scale (Q_i) for the parameters is

$$Q_i = (C_i / S_i) \times 100 \quad (2)$$

where, Ci = concentrations of water parameters, S_i = WHO and BIS drinking water standards.

Later, the sub-index (SI_i) of the parameters was calculated, and the aggregate was tabulated to give the WQI values.

$$SI_i = W_r \times Q_i \quad (3)$$

$$WQI = \sum SI_i \quad (4)$$

Afterward, the WQI values obtained were then classified using the categorization proposed by Yadav *et al*., (2010). Although DO and Po_4^{3-} are not health-based drinking water parameters under WHO (2022) guidelines, they represent primary warning indicators of organic pollution and ecosystem health in the aquatic environment. The use of both parameters for WQI is commonly used by several researchers (Chidiac *et al*., 2023).

2.5 | Irrigation Water Quality

The irrigation water qualities of the sacred ponds were calculated using parameters such as pH, EC, TDS, Sodium Percentage (Na%), Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH) and Kelly's ratio (KR), respectively.

The Na% in water represents alkali hazard to crops in irrigation water (Wilcox, 1955).

$$\%Na = [Na^+ + K^+] / [Na^+ + K^+ + Ca^{2+} + Mg^{2+}] \times 100 \quad (5)$$

The SAR in water represents sodium hazard to crops in irrigation water (Richards, 1954).

$$SAR = [Na^+] / \sqrt{[Ca^{2+} + Mg^{2+}] / 2} \quad (6)$$

The MH index is expressed by the equilibrium state of calcium and magnesium in irrigation water (Paliwal, 1972).

$$MH = [Mg^{2+}] / [Ca^{2+} + Mg^{2+}] \times 100 \quad (7)$$

The KR index represents alkali hazard due to excess alkali metal ion (Na^+) against alkaline earth metal ions (Ca^{2+} and Mg^{2+}) in irrigation water (Kelly, 1963).

$$KR = [Na^+] / [Ca^{2+} + Mg^{2+}] \quad (8)$$

Further, the irrigation water quality was assessed using Wilcox plots (Wilcox, 1955) and US Salinity Laboratory Staff (USSLS) plots (1954).

2.6 | Local's Perceptions on the Degradation and Loss of Sacred Ponds

Since the conservation of the sacred groves is done by locals, it must be understood that without local cooperation, plans or policies introduced by the authorities will never reach the desired success target. It is essential that the locals are kept as main stakeholders and their roles are strengthened. Therefore, a questionnaire survey was carried out to assess society's perception on the sacred ponds' declining conditions. The caretakers and locals from the nearby of the groves were randomly selected (N = 30 in total, with three respondents each from a sacred grove locality). The respondent's selection is restricted to people who are caretakers of the sacred groves or have permanent households in the vicinity of the sites. The interviews were conducted in Meiteilon, which is the dialect spoken by the Meitei ethnic group. Further, consent was taken before the interviews with the understanding that their anonymity would be maintained. During the interview, information such as the sacred ponds' condition, cultural significance, pollution status, encroachment level, protection by the community or government and their mechanism, and restoration and conservation status over the years were discussed and recorded (Supplementary Table 2). Afterward, analysis of the data was carried out in the Department of Environmental Science, Manipur University.

2.7 | Statistical Analysis

The results of water analysis were represented as the average of analyses ± standard deviation. Microsoft Excel 2010 was used for Na%, SAR, MH, KR, Wilcox and USSLS plots. Further, Pearson correlation analysis was used to assess any likely co-contamination of the physico-chemical characteristics of water from similar sources. It was calculated using SPSS 16.0 for Windows.

3 | RESULTS AND DISCUSSION

3.1 | Water Characteristics

The results showed temporal and spatial variations of water characteristics for PoM and PM seasons (Table 3). pH of the sampling locations for both seasons were within the permissible limit (WHO, 2022), except for S10 - Ibudhou Marjing (Table 4). The high pH in the sacred pond is attributed to surface runoff from nearby agricultural fields and pisciculture farms which use chemicals such as $CaCO_3$ to control ammonification of the aquaculture farms which are located in the surroundings.

For PM, EC values of all sacred ponds exceeded the WHO limit, i.e. 250 µS cm^{-1}. The high EC is related to practices such as bathing as a part of the religious custom, release of soaps and detergents, inflow of drainage water and agricultural runoff from the surroundings and decomposition of organic matter etc. Moreover, the phenomenon of stagnation is one of the prime reasons that cause organic matter and nutrient accumulation, thereby increasing the EC. The values were less during PoM due to rainwater dilution from heavy monsoon in the valley, with only one sacred pond (S4 - Sana Konung with 269±2.65 µS cm^{-1}) reporting values above the WHO limit (WHO, 2022).

Similar to EC, higher TDS values were observed in the PM season, which is attributed to increased evaporation, which concentrates the dissolved solids and lowers the water levels. Further, the reduction in dilution due to scanty rainfall is a reason. During the study period, TDS and EC values showed linear relationships for the sampling sites and for both seasons, which is common for freshwater ecosystems (Rusydi, 2018).

Throughout the seasons, the ponds were turbid with turbidity levels above WHO limits, viz., 5 NTU (WHO, 2022). The turbid nature is a result of soil erosion and surface runoff draining into the ponds during heavy rainfall, which introduce large amounts of silt, clay and colloidal organic matter. Further, excessive plankton growth in the ponds and their decomposition, as well as decayed leaves and plant material from the vegetation in the sacred groves, all add to turbidity. S9 - Ima Laikhut Lembi Mitinpung during PM showed the highest turbidity value of 86.9±8.75 NTU, which is linked with runoff from the surrounding agricultural fields containing suspended particles like soil, organic matter, fertilizers and pesticides, and the minimal water movement to disperse or settle these particles.

The DO level showed a drastic reduction during PM as compared to PoM, with all the sampling locations reporting low DO below WHO limits, viz., 5 mg L^{-1} (WHO, 2022). The low DO concentrations revealed the polluted status of the ponds and showed the increased biological oxygen demand (BOD) due to rapid organic matter decomposition (Yayintas *et al*., 2007). The ponds are sites for devotees to wash away their offerings in the form of leaves, flowers, fruits or vegetables etc. In short, the ponds receive a continuous supply of organic matter in the form of offerings throughout the year in large quantities. Further, stagnation of the ponds restricts natural aeration, thereby impeding effective oxygen replenishment, and traditional bathing activities and runoff introduce organic waste and dense growth of duckweed compounds to the issue.

For the ponds, human activities such as washing, bathing and urban sewage runoff could be the probable reasons for the elevated alkalinity. The high alkalinity will elevate pH and adversely affect various aquatic organisms which are sensitive to environmental change (Stumm and Morgan, 1996). S4 - Sana Konung showed the highest total hardness concentrations, *viz.* 223±4.19 mg L^{-1} as $CaCO_3$ (PoM) and 227±6.65 mg L^{-1} as $CaCO_3$ (PM), which is well above the WHO limit, i.e. 200 mg L^{-1} as $CaCO_3$ (WHO, 2022). The hardness is influenced by both carbonate and non-carbonate types, as indicated by the presence of alkaline earth metal ions, viz., Ca^{2+} (89.71±11.89 mg L^{-1} for PM and 36.14±0.43 mg L^{-1} for PoM) and Mg^{2+} (47.51±3.94 mg L^{-1} for PoM and 36.08±3.26 mg L^{-1} for PM), and alkali metal ions, viz. Na^+ (208.53±8.69 mg L^{-1} for PM and 113.2±0.87 mg L^{-1} for PoM) and K^+ (198.30±6.81 mg L^{-1} for PM and 32.83±0.19 mg L^{-1} for PoM), respectively.

As per the USGS hardness classification (US Geological Survey, 2023), 40% of the samples for PM and 30% of the samples for PoM were very hard; 70% of the samples for PM and 40% of the samples for PoM were hard and 20% of the samples for PoM were in the moderately hard category, respectively (Table 5). No soft water category was reported for the ponds. The main reason for the hardness may be lime usage as a disinfectant in the surroundings. As such, the sacred ponds showed significant presence of Ca^{2+} throughout the seasons, with the values ranging from 9.81±1.28 to 27.47±3.40 mg L^{-1} for PoM and 39.81±3.07 to 89.71±11.89 mg L^{-1} for PM, respectively. Likewise, 70% of the samples for PoM and 20% of the samples for PM have Mg^{2+} ion concentrations above the permissible limit, i.e. 30 mg L^{-1}. S7 - Hiyangthang Lairembi showed the highest Na^+ ion levels, which ranged from 113.2±0.87 mg L^{-1} for PoM to 208.53±8.69 mg L^{-1} for PM, respectively. The high sodium concentrations are because of domestic and commercial wastewater drained into the pond from the surrounding areas of Hiyangthang localities.

For both seasons, the ponds had PO_4^{3-} levels exceeding the WHO permissible limit, i.e. 0.1 mg L^{-1} (WHO, 2022). The high PO_4^{3-} content is due to lawn or agricultural runoff, sewage discharge or decaying organic matter. The ritual ceremonies performed by the devotees involving organic matter also contribute to high PO_4^{3-} content in the sacred ponds. However, NO_3^- concentrations were well below the permissible limit of 45 mg L^{-1} (WHO, 2022).

The study represents the first report of its kind to assess the water quality of the sacred ponds in the Imphal valley. However, the present study does not include heavy metals and microbiological analysis. Therefore, future research needs to cover these shortcomings.

TABLE 3 Physicochemical characteristics of the sacred ponds from the Imphal valley during (a) PoM and (b) PM seasons, 2023 - 2024.

a) PoM:

Parameters	Sample Locations									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
pH	7.30±0.06	7.40±0.10	7.25±0.03	7.30±0.03	7.01±0.02	7.32± 0.46	7.80±0.07	7.35±0.03	7.65±0.02	8.68 ±0.23
EC (µS cm^{-1})	183±3.18	137 ±2.32	136±2.08	269±2.65	193±1.79	212 ±8.08	210± 2.52	224 ±4.62	109± 1.53	142±4.62
TDS (mg L^{-1})	98.7±2.40	75.6±6.37	73.1±1.06	146.7±0.58	90.2±0.55	115.3±3.21	114±1.00	121±1.73	59.2±1.32	77.5±2.99
Turbidity (NTU)	32.80±5.60	57.8±2.57	31.03±3.50	5.27±0.31	12.10±1.71	29.57±1.84	11.87±1.55	31.17±2.48	38.90±1.59	7.03±0.91
DO (mg L^{-1})	3.3±1.56	3.9±0.71	2.9±0.42	3.3±0.42	2.9±1.56	3.0±1.41	3.5±0.14	3.5±0.99	4.5±1.27	4.7±2.69
Chloride (mg L^{-1})	46.86±1.83	20.35±1.64	18.93±0.82	54.43±2.17	20.35±1.64	66.27±4.10	66.27±2.17	55.85±3.28	17.99±0.82	11.36±1.42
Alkalinity (mg L^{-1})	31.33±1.01	26.67±6.11	89.33±1.9	26.67±5.77	35.33±1.15	31.33±1.37	30±1.42	36.67±2.02	37.33±1.05	23.33±2.43
Total Hardness (mg L^{-1} as $CaCO_3$)	190±1.58	179±3.02	138±6.00	223±4.19	113±9.02	191±6.11	175±1.17	170±7.78	117±6.11	187±3.06
Calcium Hardness (mg L^{-1})	12.90±0.97	9.81±1.28	19.90±3.97	27.47±3.40	22.43±0.45	19.62±2.70	10.65±3.97	23.55±3.36	12.62±3.36	13.46±1.46
Mg^{2+} (mg L^{-1})	43.04±2.42	41.13±7.49	28.69±1.57	47.51±3.94	22.01±4.63	41.65±1.60	39.93±4.88	35.59±3.55	25.38±1.92	42.17±0.85
Na^{+} (mg L^{-1})	73.1±8.08	35.1±1.32	28±0.25	97.3±0.36	31.9±0.85	96±0.51	113.2±0.87	111.1±0.51	42.3±0.66	64.4±0.84
K^{+} (mg L^{-1})	8.55±1.10	16.65±5.13	25.08±0.14	32.83±0.19	3.27±0.33	11.28±0.23	12.06±0.21	19.97±0.24	2.66±0.16	0.23±0.29
NO_3^{-} (mg L^{-1})	0.22±0.03	0.25±0.03	0.39±0.04	0.18±0.01	0.13±0.01	0.27±0.01	0.36±0.04	0.21±0.02	0.21±0.01	0.16±0.01
PO_4^{3-} (mg L^{-1})	0.58±0.02	0.56±0.04	0.56±0.02	0.73±0.02	0.51±0.01	0.54±0.02	0.64±0.02	0.51±0.02	0.53±0.06	0.52±0.02

b) PM:

Parameters	Sample Locations									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
pH	7.81±0.18	7.71± 0.12	7.76± 0.06	7.95 ±0.06	7.49 ±0.02	7.50±0.04	8.16 ±0.16	8.08± 0.14	7.94± 0.09	8.82±0.10
EC (µS cm^{-1})	457±2.52	355±4.01	336±5.57	681±7.43	345±3.79	635±1.58	575±3.79	426±3.46	331±1.46	347±2.65
TDS (mg L^{-1})	268±1.53	208±3.89	196±3.06	399±3.05	201±2.08	373±3.79	334±1.53	247±5.08	193±1.53	202±8.00
Turbidity (NTU)	20.87±0.68	12.67±0.49	11.30±0.91	6.57±1.80	10.87±0.73	24.53±1.77	38.01±1.66	26.07±0.32	86.9±8.75	32.6±4.13
DO (mg L^{-1})	2.4±0.57	2.1±0.14	2.1±0.14	2.6±0.005	2.4±0.57	2.1±0.71	2.4±0.57	2.7±0.42	2.4±0.28	2.9±0.14
Chloride (mg L^{-1})	56.8±2.84	22.7±1.92	27.5±1.64	72.9±5.91	47.3±2.84	85.2±3.10	85.2±4.08	60.6±6.56	23.7±8.20	14.2±0.88
Alkalinity (mg L^{-1})	103±2.31	115±4.61	117±12.06	189±8.08	95.1±5.03	118±2.88	120±7.78	121±6.11	97±7.02	149±2.06
Total Hardness (mg L^{-1} as $CaCO_3$)	159±5.03	143±7.01	132±8.72	227±6.65	140±8.11	225±6.43	175±5.14	145±2.38	172±1.58	188±8.00
Calcium Hardness (mg L^{-1})	39.81±3.07	61.12±3.70	89.71±11.89	78.50±9.42	78.50±6.60	78.50±5.69	64.48±7.00	75.69±4.45	72.89±7.18	75.69±8.25
Mg^{2+} (mg L^{-1})	28.96±1.97	19.89±1.79	29.58±1.40	36.08±3.93	14.94±1.03	35.59±3.26	26.86±1.50	16.84±2.01	24.08±3.76	27.29±4.14
Na^{+} (mg L^{-1})	92.18±0.69	44.10±0.67	34.76±0.39	133.37±3.28	59.26±4.81	164.79±16.76	208.53±8.69	140.29±10.59	77.80±0.51	98.79±1.27
K^{+} (mg L^{-1})	70.43±1.46	88.25±21.32	103.19±0.36	198.30±6.81	31.51±5.65	64.64±10.82	73.19±3.81	89.81±8.86	17.65±0.06	1.64±1.07
NO_3^{-} (mg L^{-1})	0.97±0.08	0.71±0.04	2.24±0.09	1.60±0.11	2.01±0.45	1.93±0.04	2.30±0.06	1.17±0.09	1.31±0.06	1.22±0.01
Po_4^{3-} (mg L^{-1})	0.16±0.03	0.18±0.03	0.42±0.05	0.30±0.04	0.21±0.03	0.22±0.01	0.19±0.01	0.26±0.03	0.16±0.03	0.29±0.03

TABLE 4 Classification of the sacred ponds from the Imphal valley according to WHO guidelines for drinking water standards.

S.No	Parameters	WHO permissible limits (WHO, 2022)	Percentage of samples beyond permissible limits	
			PoM	PM
1	pH	6.5-8.5	10	10
2	EC (µS cm^{-1})	250	10	100
3	TDS (mg L^{-1})	500	0	0
4	Turbidity (NTU)	5	100	100
5	DO (mg L^{-1})	5	100	100
6	Chloride (mg L^{-1})	250	0	0
7	Alkalinity (mg L^{-1})	200	0	0
8	Total Hardness (mg L^{-1} as $CaCO_3$)	200	10	20
9	Mg^{2+} (mg L^{-1})	30	70	20
10	Ca^{2+} (mg L^{-1})	75	0	60
11	Na^+ (mg L^{-1})	200	0	10
12	NO_3^- (mg L^{-1})	45	0	0
13	PO_4^{3-} (mg L^{-1})	0.1	100	100

TABLE 5 Total hardness classification of the sacred ponds water from the Imphal valley.

S.No	Hardness classification	Hardness range (mg L^{-1} as $CaCO_3$) (USGS, 2023)	Percentage (%) of samples	
			PoM	PM
1	Soft	0-60	0	0
2	Moderately hard	60-120	20	0
3	Hard	120-180	40	70
4	Very hard	> 180	40	30

3.2 | Correlation Analysis

The interrelationship between water quality parameters of the ponds and their co-variability for both seasons are presented in Table 6.

For PoM, a strong positive correlation was found between pH and DO; EC and TDS, Na^+, Cl^- and PO_4^{3-}; TDS and EC, TH, Mg^{2+}, Na^+ and Cl^-; TH and Mg^{2+} and PO_4^{3-}; Na^+ and Cl^-, respectively. The EC and TDS showed a strong correlation (r = 0.829), which showed that increased EC may be related to the dissolved inorganic ions present in the surface runoff, domestic effluent and agricultural runoff, etc.

Moreover, EC is strongly correlated with Na^+ (r = 0.758), Cl^- (r = 0.796) and PO_4^{3-} (r = 0.703), indicating that the presence of inorganic dissolved ions such as sodium, chloride and phosphates results in higher EC.

For PM, strong correlations were observed between EC and TDS, TH, Na^+ and Cl^-; TDS and TH, Na^+ and Cl^-; TH and Mg^{2+}, and Na^+ and Cl^-, respectively. Na^+ is strongly correlated with Cl^- for both seasons (r= 0.893 for PoM and r = 0.821 for PM). Na^+ and Cl^- often occur together as part of NaCl. When Cl^- levels are high, a corresponding increase in Na^+ levels may be indicated due to their common association with dissolved salts.

3.3 | Water Quality Characterization

3.3.1 | Drinking Water Quality

During the study period, temporal and spatial variations of WQI values were observed (Fig. 3).

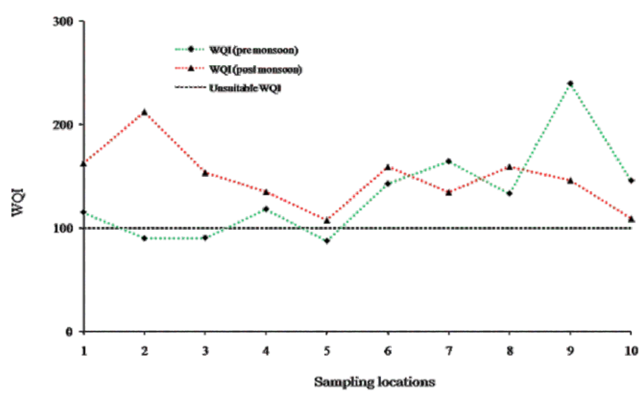


FIGURE 3 Spatial variation of WQI in the sampling locations of ten sacred ponds.

TABLE 6 Pearson correlations among sacred ponds water characteristics from the Imphal valley.

a) PoM:

	pH	EC	TDS	DO	Turbidity	Alkalinity	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	No_3^{-}	Po_4^{3-}
pH	1	-.325	-.039	**.806**	-.359	-.294	.237	-.481	.328	.150	-.405	-.230	-.406	-.126
EC		1	**.829**	-.530	.183	.048	.575	.409	.656	**.758**	.506	**.796**	.116	**.703**
TDS			1	.255	-.166	-.025	**.819**	.403	**.711**	**.880**	.630	**.849**	.010	.692
DO				1	-.292	-.029	.001	-.549	.196	-.099	-.466	-.446	-.324	-.462
Turbidity					1	**.785**	-.101	.137	.008	-.118	-.411	.023	**.809**	-.045
Alkalinity						1	-.049	-.161	.128	.085	-.446	.223	**.870**	-.248
TH							1	.106	**.932**	.642	.438	.553	.018	**.728**
Ca^{2+}								1	-.106	.216	.553	.252	-.012	.305
Mg^{2+}									1	.652	.165	.531	.107	.562
Na^{+}										1	.259	**.893**	.059	.451
K^{+}											1	.365	-.318	.652
Cl^{-}												1	.281	.509
No_3^{-}													1	-.160
Po_4^{3-}														1

b) PM:

	pH	EC	TDS	DO	Turbidity	Alkalinity	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	No_3^{-}	Po_4^{3-}
pH	1	-.123	-.130	.423	.283	.442	.144	-.003	.023	.233	-.238	-.291	-.213	-.142
EC		1	**1**	-.470	-.189	.553	**.788**	-.064	.554	**.774**	.611	**.879**	.294	.059
TDS			1	-.470	-.192	.553	**.791**	-.066	.562	**.767**	.612	**.876**	.289	.059
DO				1	.371	-.356	-.120	-.221	-.113	-.149	-.841	-.441	-.008	-.505
Turbidity					1	-.318	.128	-.063	.072	.181	-.547	-.169	-.159	-.554
Alkalinity						1	.619	.246	.473	.298	.636	.187	-.008	.333
TH							1	.108	**.831**	.600	.256	.499	.120	-.123
Ca^{2+}								1	-.168	-.097	.078	-.128	.537	.648
Mg^{2+}									1	.242	.196	.250	-.330	-.263
Na^{+}										1	.163	**.821**	.310	-.199
K^{+}											1	.439	.088	.558
Cl^{-}												1	.432	.005
No_3^{-}													1	.483
Po_4^{3-}														1

Bold: Correlation is significant.

For PoM, WQI ranged from 107.29 to 211.91. It ranged from 87.46 to 239.51 for PM (Table 7). The high WQI value in PoM, compared to the PM season, is due to the large amount of pollutants and nutrients inflowing through surface runoff as a result of heavy monsoon. For example, higher PO_4^{3-} concentrations ranging from 0.51±0.01 to 0.73±0.02 mg L^{-1} were observed in PoM. The WQI for drinking reflects the cumulative impact of specific individual water parameters compared against the permissible limits. Based on the WQI values obtained, 100% of the PoM samples were in the unsuitable category.

For PM, 70% of the samples were in the unsuitable category and 30% of the samples in the very poor category. Throughout the seasons, the sacred ponds during the study period of 2023 - 24 were not safe for drinking. However, the devotees will normally use the ponds whenever they visit the sacred sites. The sacred sites are one of the most frequently visited places in the valley for a number of ritualistic ceremonies. For example, the sacred sites of S3 - Mahabali (WQI value of 153.47 for PoM and 90.42 for PM), S4 - Sana Konung (WQI value of 134.77 for PoM and 118.09 for PM), S5 - Puruk Shoubi (WQI value of 107.29 for PoM and 87.46 for PM) and S8 - Shri Shri Govindaji (WQI value of 159.09 for PoM and 133.28 for PM) will have visitors in the count of hundreds every day.

Therefore, the results showed that sacred ponds are unsuitable for normal use by the devotees. Moreover, the degraded water quality will be problematic for the wild biodiversity that seeks refuge in the protected area. For example, at the sacred site of S3 - Mahabali, hundreds of wild monkeys take refuge at the abode of the Hindu god - Hanuman.

TABLE 7 Water quality categorization based on the calculated WQI values (Yadav *et al.*, 2010) of ten sacred ponds from the Imphal valley.

Sampling locations	Post Monsoon		Pre- Monsoon	
	WQI value	Interpretation	WQI value	Interpretation
S1	162.39	Unsuitable	115.14	Unsuitable
S2	211.91	Unsuitable	89.95	Very poor
S3	153.47	Unsuitable	90.42	Very poor
S4	134.77	Unsuitable	118.09	Unsuitable
S5	107.29	Unsuitable	87.46	Very poor
S6	158.87	Unsuitable	142.63	Unsuitable
S7	134.36	Unsuitable	164.28	Unsuitable
S8	159.09	Unsuitable	133.28	Unsuitable
S9	145.88	Unsuitable	239.51	Unsuitable
S10	108.91	Unsuitable	145.70	Unsuitable

3.3.2 | Irrigation Water Quality

Ponds have been a reliable source of irrigation water for generations since they allow the users to have water on demand because of the ponds' built-in flexibility to store water near water users (Loeve *et al*., 2021). However, the sacred ponds have never been fully exploited for irrigation. But, the water is still used by caretakers to maintain the gardens in the groves themselves.

During the study period, S-10 Ibudhou Marjing had pH values of 8.68 ± 0.23 for PoM and 8.82±0.10 for PM, respectively (Table 8). As such, irrigation with alkaline water will limit the availability of essential nutrients such as phosphorus and affect plant growth (Wu *et al*., 2021). EC values were in the excellent and good categories (Richards, 1954). Likewise, TDS values were in the freshwater category (Freeze and Cherry, 1979).

The Wilcox diagram plots between Na% and EC for both seasons showed that the pond water is in the excellent to good category, indicating that vulnerability to sodium hazard or problems associated with EC are lower (Fig. 4). The USSLS diagram plots showed that 60% of the samples for PoM and 30% of the samples for PM were in the medium salinity hazard category (C2-S1), respectively (Fig. 5).

Further, 20% of samples for PoM and 30% of samples for PM showed KR values in the unsuitable category (Kelly, 1963). The irrigation of fields with water that has a KR value greater than 1 will reduce the soil's water infiltration capacity and thereby make it impervious and compact (Aboukarima, 2018). For PoM, 100% of samples have MH values in the unsuitable category. On the contrary, for PM samples, 90% were in the safe category (Paliwal, 1972).

The high Mg^{2+} ion presence in irrigation water will increase soil alkalinity and reduce the availability of Ca^{2+} ions to plants, thereby affecting their growth (Tanaya, 2024; Chandrakala *et al*., 2025). Therefore, the use of the sacred ponds as irrigation sources will expose the plants to pH stress, and excess exposure to Na^+ and Mg^{2+} is detrimental.

TABLE 8 Classification of the sacred ponds water from the Imphal valley for Irrigational use based on pH, EC, TDS, Na%, SAR, MH and KR.

Parameters	Range	Class	Percentage (%) of samples	
			PoM	PM
pH (Ayers and Westcot, 1976)	< 6.5	Suitable	0	0
	6.5-8.4	Desirable	90	90
	> 8.4	Unsuitable	10	10
EC ($\mu S\ cm^{-1}$) (Richards, 1954)	< 250	Excellent	90	0
	250-750	Good	10	100
	750-2000	Permissible	0	0
	2000-3000	Doubtful	0	0
	> 3000	Unsuitable	0	0
TDS ($mg\ L^{-1}$) (Freeze and Cherry, 1979)	<1000	Freshwater	100	100
	1000-3000	Slightly saline	0	0
	3000-10000	Moderately saline	0	0
	10000-35000	Highly saline	0	0
	> 35000	Brine	0	0
Na% (Wilcox, 1955)	< 20	Excellent	0	0
	20-40	Good	50	0
	40-60	Permissible	50	90
	60-80	Doubtful	0	10
	> 80	Unsuitable	0	0
SAR (Bouwer, 1978)	< 6	No Problem	100	100
	6-9	Increasing Problem	0	0
	> 9	Severe Problem	0	0
KR (Kelly, 1963)	< 1	Safe	80	70
	> 1	Unsuitable	20	30
MH (Paliwal, 1972)	< 50	Safe	00	90
	> 50	Unsuitable	100	10

Notes: MH - Magnesium Hazard; SAR - Sodium Adsorption Ratio; KR - Kelly's ratio.

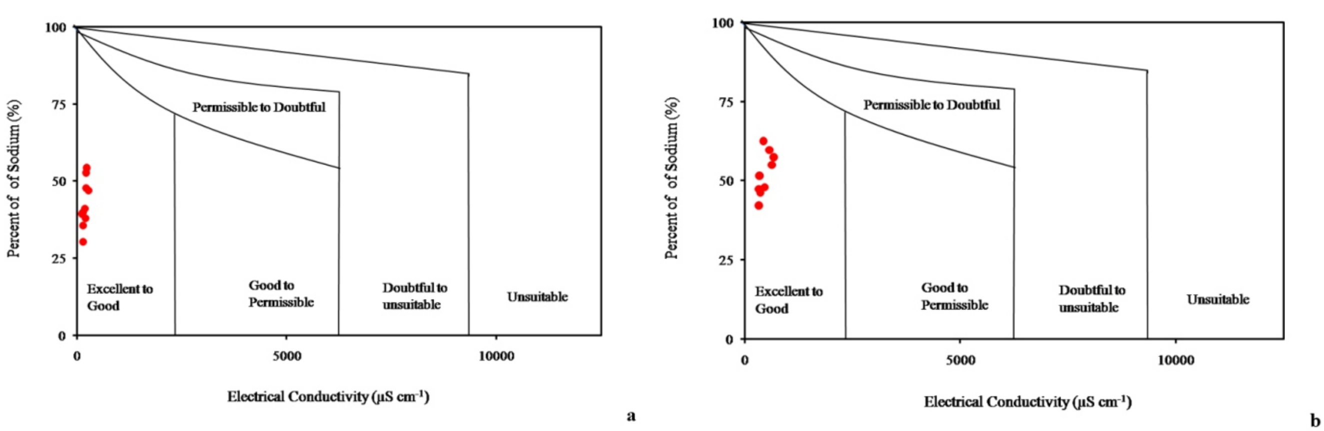


FIGURE 4 Wilcox diagram plots between Na^+ and EC of sacred ponds water for (a) PoM and (b) PM.

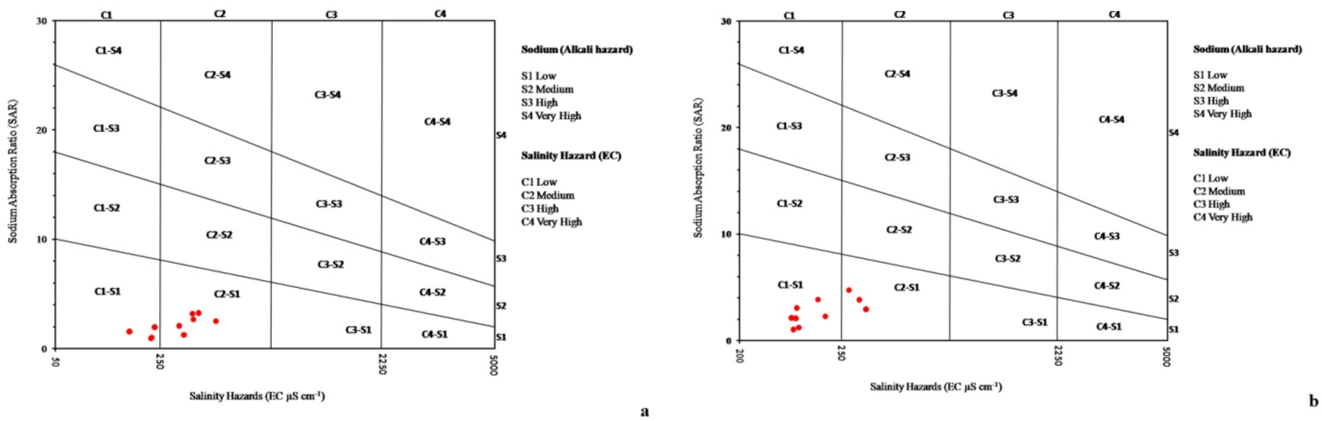


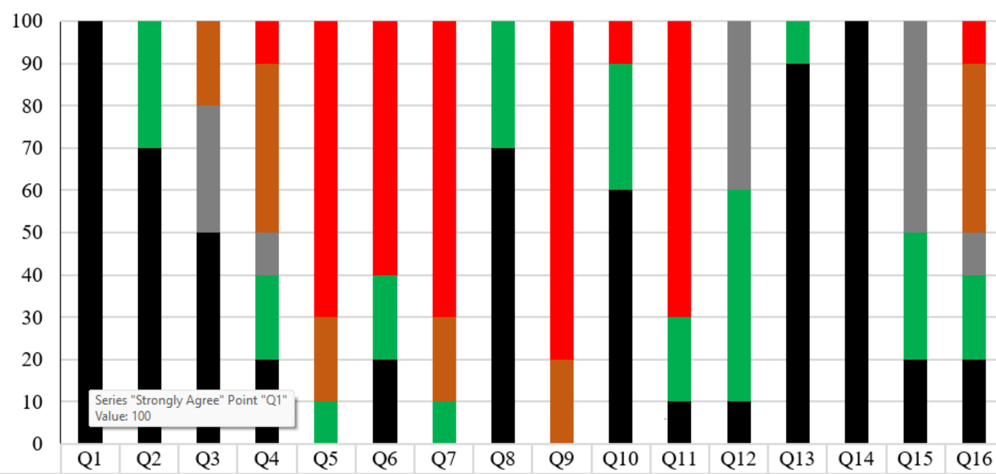
FIGURE 5 USSLS diagram plots between SAR and EC of sacred ponds water for (a) PoM and (b) PM.

3.4 | Local's Perception on the Conditions of the Sacred Ponds

Fig. 6 shows that the majority of locals who participated in the survey agree that the ponds hold significant cultural significance (100%). Further, the respondents agree with the statement that the ponds are utilized by the devotees in religious prayers or ceremonies. Likewise, they do believe that spiritual or cultural influence is keeping the ponds alive. With respect to the main stakeholders in conservation, the participants involved in the survey (60% strongly agree and 30% agree) said that the ponds are protected by locals. However, it was disheartening to see that 20% of local respondents believe the ponds are no longer choice habitats for biodiversity. Further, 30% of the locals who participated didn't have any comment on the question. It showed that the sacred ponds as habitats for wildlife in the Imphal valley are questionable today.

The locals who participated in the survey have divided opinions on whether ecological changes are seen in the ponds, with 40% agreeing and 50% disagreeing, respectively. According to the locals (90%), encroachment is never an issue. But the locals (40%) agree with the statement that pollution is becoming a problem. However, the majority of locals (90%) disagree that pollution is happening due to untreated sewage runoff from the surrounding areas.

Further, the locals participated in the survey do believe that the ponds must be protected by implementation of any mechanism whatsoever is necessary. Regular monitoring of the health status of the ponds is a necessity that must be addressed as per the opinions of the locals. Moreover, some of the locals added that the lack of scientific studies on the ponds' ecological health is a serious issue in the Imphal valley at the moment.



	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Strongly Disagree	0	0	0	10	70	60	70	0	80	10	70	0	0	0	0	10
Disagree	0	0	20	40	20	0	20	0	20	0	0	0	0	0	0	40
Can't Say	0	0	30	10	0	0	0	0	0	0	0	40	0	0	50	10
Agree	0	30	0	20	10	20	10	30	0	30	20	50	10	0	30	20
Strongly Agree	100	70	50	20	0	20	0	70	0	60	10	10	90	100	20	20

FIGURE 6 General perceptions of locals on the loss of sacred ponds and its associated ecosystem services from the Imphal valley.

From the discussions, it was observed that the locals who participated in the survey were quite aware of the significant nature of the ponds for society. However, the status of the ponds is something that locals have never tried to study or care about.

In the end, although the ponds play an irreplaceable role in Meitei society, they remain untouched when conservation is discussed. The conservation plans implemented so far for the sacred groves never had significant strategies for the sacred ponds' rejuvenation or restoration.

4 | CONCLUSIONS

From the study, it was observed that urbanization, pollution, generational culture shifts and lack of awareness are some of the issues that threaten the sacred ponds. The water characteristics analysis showed that most of the sacred ponds are in a dire state. For example, the sacred pond at the sacred site of S4- Sana Konung showed high EC (269±2.65 µS cm^{-1} during PoM and 681±7.43 during PM), high TH (223±4.19 mg L^{-1} during PoM and 227±6.65 mg L^{-1} during PM), and high Ca^{2+} (78.50±9.42 during PM), which are well above WHO limits during the study period. Today, most of the ponds' water quality is unsuitable for drinking. Even though local participation has been protecting the sacred ponds to date, integration of traditional socio-cultural knowledge with modern conservation strategies to safeguard the ecological and cultural heritages is still missing. Therefore, it is timely that proper in-depth scientific studies that assess the ecological health of such significant ponds are carried out; community engagement is strengthened, and effective environmental regulations are implemented for the revival of the holy sites and their associated sacred ponds in the Imphal valley.

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DATA AVAILABILITY STATEMENT

The authors declare that the data supporting the findings of this study are available within the paper.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

AUTHOR'S CONTRIBUTION

Khoirom Alina Devi: Investigation, Methodology, Writing - Original Draft, Writing - Review & Editing. Maibam Dhanaraj Meitei: Conceptualization, Investigation, Methodology, Supervision, Writing - Original Draft, Writing - Review & Editing. DP Tungyairan: Writing - Review & Editing. Irungbam Bandana Devi: Writing - Review & Editing. Soram Korouhanbi Chanu: Writing - Review & Editing.

Supplementary data available in online version.

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